working pressure of the forming fluid to assure that a peeling action progressively occurs while a laminate is being formed into a hollow object. The annealing treatment, however, is a highly useful measure for introducing a greater reluctance to separation of the bond under the working load and accordingly promotes a greater distention of those portions of the laminate which are to enter the cavities of the die as an incident to the forming operation, the distention being more progressive before the bond is entirely broken within the boundaries of the die wall. In certain instances, too, advantage is found in only partially forming the laminate in the die, this step, for example, terminating at a stage where the layers have been peeled apart entirely within the prescribed limits of the die by full expansion though conformity with the die wall has not yet occurred. To relieve the working stresses at this point, the partially worked product is removed from the die and subjected to an annealing treatment which not only relieves stresses which have accrued especially where cold working has been practiced to arrive at the partially completed product but a strengthening of the bond may even be developed at this point by recrystallization particularly where the earlier annealing step for this purpose has been omitted. Of further importance, the metal is softened by the annealing and is more responsive to further working in the die. Then, by placing the partially expanded product back into the die and continuing with the application of fluid under pressure to the hollow zone, the laminate is fully expanded into contact with the faces of the die and accordingly thereafter is removed. Annealing of the final product also is often practiced to strengthen the weld which remains between the several layers outside the hollowed out portion.

Accordingly, it will be appreciated that the process described herein is well suited to the manufacture of many different types of hollow products and that the process is a highly practical one which promotes effective working of laminated sheet material under conditions where stresses of the working are distributed to good advantage. The peel-bonded laminates are easily produced and allow a considerable tolerance in the die for proper placement for the expanding action of the fluid subsequently to ensue giving products of hollow form. The reluctance of the bond to separation at the outset causes the working forces to be applied at the outset to less than the whole area which ultimately is to be acted on by the fluid. This manner of working introduces practical advantages and has been found to give a more uniform overall working action on the sheet material. Cold working the laminate by fluid pressure is feasible to distend the appropriate areas into the die cavities and the process alternatively permits hot working procedures in lieu of cold working especially where the characteristics of the sheet material being used and the nature of the product being produced suggests that it is most feasible to follow that practice. In all, the process not only offers considerable latitude over specific practices which may be followed to accomplish the end result, but for such reasons as the laminates called for the method is easy to practice permitting working tolerances in inserting the laminate in the die and forming the laminate and further accomplishing a deformation in which necking-in is substantially avoided.

Thus, it will be seen that with this invention the various objects noted herein together with many thoroughly practical advantages are successfully achieved. Peel-bond characteristics of the laminates used and peeling by pressure exerted on these laminates contribute highly useful and worthwhile results all with substantial advancement of the art.

While particular emphasis has been placed on the production of hollow sheet metal products, and especially those made from aluminum and its alloys, it will be distinctly understood that certain other worthwhile hollowed out products such as those of synthetic resin sheet laminates, or laminates including synthetic resin and metal sheets compositely, also may be made in accordance with the method of this invention still with certain advantages.

As many possible embodiments may be made of this invention and as many possible changes may be made in the embodiments hereinbefore set forth, it will be distinctly understood that the matter described herein is to be interpreted as illustrative and not as a limitation.

The bond strength developed between the sheets prior to inflation should generally be less than the yield strength of the metal to be expanded into the die, but sufficient that the resulting product is capable of withstanding the pressure to be encountered during use. Thus, one of the limiting conditions for use of the product as a pressure vessel is bursting of the passageway formed in the sheet. That is largely a calculable matter, however, since it is dependent primarily upon the metal alloy involved, the thickness of the sheets, and the cross-sectional configuration of the passageway.

The possibility that the inflated sheet will fail by peeling before bursting is another limiting condition which depends on the magnitude of the bond strength compared to the bursting strength. The bond between adjacent sheets is weak enough to be forceably broken by the application of high-pressure inflating fluid without unduly distorting the metal, but strong enough that following inflation and removal from the die the unsupported sheet is capable of withstanding an internal pressure substantially in excess of 100 p.s.i. without peeling apart adjacent the passageway. This condition is satisfied, employing the procedures set forth herein by use of stop-weld material constituting about 50% of the area to be expanded, as previously mentioned. For a lesser proportion of stop-weld material, the strength of the bond will be even greater. For example, when sheets of 1100 aluminum are weld-bonded in substantially face-to-face contact, with little or no stop-weld material interposed but otherwise in accordance with the practice described in the foregoing examples, the bond is such that the resulting inflated sheet product will withstand at least 500 p.s.i. without failure due to peeling. In that case, the failure condition for applied pressure up to 500 p.s.i. will be bursting rather than peeling, and at higher pressure it may be either bursting or peeling.

Another measure of the bond strength achieved in the practice of the invention is the pressure required to delaminate the welded sheets. In general, the pressure to delaminate will be substantially greater than 500 p.s.i. (ordinarily 1500 p.s.i. or more) since the effect must be such as to not only break the bond but also to stretch and expand the metal into the die cavity.

What is claimed is:

1. In making hollowed products by selective expansion of areas of a multi-layer laminate, the process which comprises

supporting in a die a multi-layer laminate characterized by having adjacent layers peelably bonded together at the interface therebetween including at least a substantial part of said interface in the areas thereof to be expanded,

introducing fluid under pressure between said adjacent layers where the bond is,

breaking said bond in an increment of the area to be expanded,

progressively working and expanding the thus separated portion of at least one of said layers into said die by the pressure of said fluid while said layers in an adjacent increment of said area to be expanded are restrained from peeling by said bond,

continuing to progressively break said bond in successive increments of the area to be expanded, along the direction in which the fluid flows,